Maxwell James Smith
[redacted]

Dear Committee Members:

**SUBMISSION: INQUIRY INTO ONSHORE UNCONVENTIONAL GAS IN VICTORIA**

Thank you for the opportunity to provide a submission to this timely and important inquiry.

My submission relates to the environmental, land productivity and public health risks of onshore unconventional gas activities; coexistence of onshore unconventional gas activities with existing land and water uses, as well as resource knowledge requirements and policy and regulatory safeguards. I make this submission with particular reference to coal seam gas (CSG), to the environmental and health impacts of onshore gas activities, the issue of well integrity, to effects on ground and surface water systems, and to the inadequacy of industry regulation in other Australian jurisdictions.

I have identified significant gaps in the scientific data informing the assessment and management of onshore gas activity, and note that there is considerable uncertainty surrounding the science of onshore gas extraction.

The independent scientists and studies cited in this submission have raised concerns regarding the substantial risks posed by onshore gas activities to groundwater, the environment and human health.

I note that the recent NSW Chief Scientist and Engineer's Report of the Independent Review of Coal Seam Gas Activities in NSW ('the Report') identifies the main gaps in scientific knowledge relating to CSG and onshore gas extraction, but has not undertaken an in-depth study to assess the risks identified. Indeed, no such study has yet been undertaken in Australia.

The Report also acknowledges this limitation, stating that data collection and assessment must be carried out over an appropriate period of time in order to develop meaningful and credible scientific models.

This submission concludes that regulatory decisions for onshore gas activities are made with reliance on inadequate data. As such, regulation of onshore gas activity cannot be sufficient to manage the potential risks of such activity to water, environment, land productivity, and human health.

The submission also finds that regulatory decision makers in Australia have not adequately addressed the management of risk arising from the lack of quality in the currently available data. There are further gaps with regard to compliance monitoring.

The submission therefore recommends that a precautionary approach be applied to assessment and management of onshore gas activity.

I call upon the Committee to recognise the scientific concerns raised in this submission about the lack of adequate scientific data and the potential risks of onshore unconventional gas activity, particularly in regards to the environmental, land productivity and public health risks.

I urge urge the Committee to adopt a considered and informed precautionary response to these findings, and consider the benefits of a perpetual ban on onshore unconventional gas in Victoria.

**IMPACTS OF COAL SEAM GAS ON GROUNDWATER.**

Groundwater is often extracted as part of the production of coal seam gas from underground reserves.[1] This is because groundwater pressure keeps the gas absorbed between layers of coal. In order to reduce the water pressure and release the gas, large quantities of groundwater, known as produced water, must be pumped out of the coal seams. This process of removing water pressure from the coal seams is referred to as 'de-watering'.

HOW MUCH GROUNDWATER IS EXTRACTED BY COAL SEAM GAS PRODUCTION?

There is much uncertainty and debate about the amount of water the coal seam gas industry extracts from underground sources, as independent science has struggled to keep up with the rapid development of CSG in Australia.

Accurately quantifying CSG water extraction in Australia is also difficult. This is because of the lack of available data, and the many variables in water extraction rates between different wells, the structure and geology of different coal seam formations, and depth of the coal seam.

Estimates of the groundwater impacts of CSG production in Australia differ greatly between industry analysis and other scientific reports.

For example, 'the Water Group' expert panel, in its 2010 report to the Australian Government, predicted total CSG water extraction from the Great Artesian Basin at volumes of up to 1,500 gigalitres per year – 22 times more than predicted by CSG industry proponents.[2]

To put this scale of water in perspective, one 'gigalitre' is a billion litres of water (or approximately 400 Olympic-size swimming pools), and 540 gigalitres per year is the approximate annual groundwater extraction from the Great Artesian Basin by all existing water uses.[3]

Staggeringly, the Water Group found that their estimates of CSG water extraction rates actually exceed aquifer recharge levels of the area.[4] This could cause a pressure gradient leading groundwater to flow away from local springs, leaving springs and possibly dependant river systems without water flow.[5]

The Water Group also noted that groundwater extractions could be even greater than those predicted by their own analysis, because of the connections and flow of water between different ground and surface water sources.[6]

In summarising its findings, the Water Group expressed serious concern at "the general level of uncertainty associated with [CSG] proposals, and the inability of proponents to accurately quantify their individual and collective impacts over the life of their projects"[7].

On a national scale, The National Water Commission conservatively estimates the volumes of water usage from CSG at over 300 gigalitres per year.[8] That amount of water would fill approximately two thirds of Sydney Harbour, or 120,000 Olympic-size swimming pools each year![9]

WHAT DOES THIS MEAN FOR GROUNDWATER LEVELS?

There is an obvious risk that the extraction of such large volumes of groundwater from the coal seams and resulting changes in pressures may lower water tables and reduce the water resources available in connected surface-waters and groundwater systems.[10] Some of those systems, such as the Great Artesian Basin and the Murray-Darling Basin may already be fully or over-allocated.[11] This can have negative affects for other water users and the environment.[12]

It has previously been acknowledged by proponents in the CSG industry that the "drawdown of ground water heads within coal seam gas aquifers is a necessary process and an unavoidable impact associated with the depressurisation of the coal seam"[13].

The National Water Commission has stated:

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[1] RPS Australia (2011), 'Onshore co-produced water: extent and management', *Waterlines Report Series no 54*, September 2011, National Water Commission, Canberra, at 5.
[2] WG (2010) Water Group Advice On EPBC Act Referrals Referral - 2008/4399 Santos-Petronas Referral - 2008/4059 And Comments On Ap Lng Referral - 2009/4974, Based On Information Provided By The Proponents To Close Of Business 03/09/10, Water Group, September 2010, at 10.
[3] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra; RPS Australia (2011), at p. *vii.*
[4] WG (2010), at 5-6, 15.
[5] WG (2010), at 5-6, 15.
[6] WG (2010), at 10-11. See: Hodgkinson, J., Hortle, A., and McKillop, M. (2010). *The application of hydrodynamic analysis in the assessment of regional aquifers for carbon geostorage: preliminary results for the Surat Basin, Queensland.* APPEA Journal 50, 445-462.
[7] WG (2010), at 3.
[8] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra. See: NWC (2012) Coal seam gas update—June 2012, National Water Commission, Canberra. http://nwc.gov.au/nwi/position-statements/coal-seam-gas:
The National Water Commission estimate of water production from CSG wells at 300GL/year was based on an assessment of average water production per energy unit in each production basin of CSG reserves. This 'water to energy ratio' method was used because energy information is widely and nationally available. Whilst the 300 GL/year estimate was based on data available in 2008–09, it remains an independent national estimate that is backed by a transparent method using publicly available data sources that are clearly referenced.
[9] See: NSW Irrigators Council, 'Useful Water Comparisons': http://www nswic.org.au/pdf/fact_sheets/USEFUL%20WATER%20COMPARISONS.pdf
[10] Williams, J., Stubbs, T. & Milligan, A. (2012) *An analysis of coal seam gas production and natural resource management in Australia: Issues and Ways Forward*, A report prepared for the Australian Council of Environmental Deans and Directors (ACEDD) by John Williams Scientific Services Pty Ltd, Canberra, Australia, at 42; CEDA (2012), at 30; Hillier, J. (2010) Groundwater Connections Between the Walloon Coal Measures and the Alluvium of the Condamine River. A report for the Central Downs Irrigators Ltd, August 2010; Moran, C. & Vink, S. (2010) Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin. Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland, November 2010; WG (2010).
[11] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra, at 1. http://www nwc.gov.au/__data/assets/pdf_file/0003/9723/Coal_Seam_Gas.pdf
[12] CEDA (2012), Australia's Unconventional Energy Options, September 2012, The Committee for Economic Development of Australia, Melbourne, at 30.
[13] Groundwater (Deep Aquifer Modeling) for Santos GLNG Project – Environmental Impact Statement 31/3/2009.
See: University of Southern Queensland (2011) *Preliminary assessment of cumulative drawdown impacts in the Surat Basin associated with the coal seam gas industry: investigation of parameters and features for a regional model of Surat Basin Coal Seam Gas developments.* Technical Report, March 2011, University of Southern Queensland, Australia.

> "Although it is not always apparent, surface water in many rivers, dams, lakes and wetlands is connected to underground water resources in aquifers.... This connectivity means that issues such as over-extraction… could impact on the water quantity and quality in both ground and surface water systems."[14]

A 2012 report from the Committee for Economic Development Australia, stated that CSG, "can cause a variety of water impacts – depleting aquifers and streams connected to those aquifers, changing groundwater quality"[15].

A study by Moran and Vink into the impacts of CSG to the Murray-Darling Basin also suggests that changes in groundwater pressures due to dewatering can result in localised changes in water quality.[16]

A 2012 study by the Queensland Water Commission also found a definitive link between bore water levels and coal seam gas operations.[17] The Underground Water Impact Report identified 85 wells in Queensland at risk of running out of water supply within 3 years, and a further 528 wells that are likely to be similarly impacted by CSG operations in the long-term.[18]

The ability to quantify the effects of CSG water extraction on groundwater levels is restricted by a lack of available data and uncertainties of geological and hydrological science.[19] The level of CSG impacts on groundwater pressures will differ depending on the physical make-up and other geological characteristics of effected basins, as well as the quantity of water extracted and the rate of aquifer recharge.[20] It may take years, and even decades, for the full extent of groundwater drawdown across aquifers to be realised.[21] Moreover, it could take centuries for effected aquifers to recharge.[22]

But one thing is clear: "if there is depressurisation of groundwater at depth, there will be changes to the whole groundwater regime."[23]As hydrogeologist Phillip Pell explains, "it is not a matter of 'if', it is a matter of 'how long' will it take for the effects to be transmitted through the system"[24].

Much more research is needed to identify and understand the interaction of connected water resources in areas where CSG is proposed. As Williams, Stubbs & Milligan (2012) write, echoing the sentiments of The National Water Commission, "the large amount of water and the large range of the estimates are excellent grounds for applying a precautionary approach."[25] This means that CSG projects should not be approved without comprehensive analyses of groundwater impacts and the development of secure management plans, which reflect and make-good on these cumulative impacts on our water resources. Otherwise, as Williams, Stubbs & Milligan remark, "it would be folly to secure one natural resource while putting at risk renewable long-term resource use."[26]

### WHAT IS THE GOVERNMENT DOING ABOUT THIS?

Unfortunately, due to the rapid development of the CSG industry in Australia, governments have been unable to keep up. The regulatory response in Queensland and NSW has been piecemeal and lacks the capacity to manage extent of potential CSG impacts on water.[27]

Currently, the approval process for CSG projects is generally based on assessment undertaken by the gas companies seeking to develop CSG projects. It is unlikely that industry would undertake the necessary research on groundwater impacts before projects are submitted for approval.[28]

Geoscience Australia, in advice to the Federal Government, stated that the impacts assessments by CSG project proponents are "unavoidably inadequate because of the inability of individual proponents to access commercial-in-confidence data from a number of sources"[29].

This approach to risk assessment on a project-by-project basis does not take into account the cumulative impacts of CSG on our water.

It is of concern that, by using the NSW 'State Significant Development' approach, the largest CSG projects are not subject to many of the checks and balances in the system which safeguard our groundwater.[30] For example, such state-significant CSG

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[14] SCRAT (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, November 2011, Senate Standing Committee on Rural Affairs & Transport, Canberra, at 17.
[15] CEDA (2012), at 28.
[16] Moran, C. & Vink, S. (2010) Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin. Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland, November 2010: at 4, 21-27.
[17] Queensland Water Commission (2012) Underground Water Impact Report for the Surat Cumulative Management Area. Office of Groundwater Impact Assessment, Queensland Government Department of Natural Resources and Mines, July 2012, Brisbane: http://dnrm.qld.gov.au/__data/assets/pdf_file/0016/31327/underground-water-impact-report.pdf
[18] Queensland Water Commission (2012), at x-xii, 53-58.
[19] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra.
[20] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra.
[21] SCRAT (2011), at 19.
[22] SCRAT (2011), at 19-20; Pells, S. & Pells, P. (2012) Impacts of Longwall Mining and Coal Seam Gas Extraction on Groundwater Regimes in the Sydney Basin, Australian Geomechanics Journal, Vol 47(3), September 2012, at para 2.3.2; CSIRO (2012) Coal seam gas developments—predicting impacts, April 2012, at 1; Geoscience Australia & Dr Habermehl M.A. (2010) Summary Of Advice In Relation To The Potential Impacts Of Coal Seam Gas Extraction In The Surat And Bowen Basins, Queensland Phase One Report Summary For Australian Government Department Of Sustainability, Environment, Water, Population And Communities provided by Geoscience Australia and Dr M.A. Habermehl, Canberra, 29 September 2010; Water Group (2010).
[23] Pells, P. (2012) Key Issues in Relation to Coal Seam Gas Extraction in New South Wales, Memorandum prepared on behalf of Pells Consulting P034.M1, 13 March 2012, at 9.
[24] Pells, P. (2012), at 9.
[25] Williams, Stubbs, & Milligan, (2012), at 47.
[26] Williams, Stubbs, & Milligan, (2012), at 5, 102.
[27] Williams, Stubbs, & Milligan, (2012), at 89.
[28] SCRAT (2011), at 27.
[29] Geoscience Australia & Dr Habermehl M.A. (2010) Summary Of Advice In Relation To The Potential Impacts Of Coal Seam Gas Extraction In The Surat And Bowen Basins, Queensland Phase One Report Summary For Australian Government Department Of Sustainability, Environment, Water, Population And Communities provided by Geoscience Australia and Dr M.A. Habermehl, Canberra, 29 September 2010.
[30] Williams, Stubbs, & Milligan, (2012), at 88, 89.

developments are exempt from the need to hold an aquifer interference approval for dewatering activities where they intersect with an aquifer.[31]

[31] Williams, Stubbs, & Milligan, (2012), at 89. See: NSW DoPI (2012) Draft NSW Aquifer Interference Policy — Stage 1. NSW Government Department of Trade and Investment, Regional Infrastructure and Services, 2012.

**WATER CONTAMINATION**

Coal seam gas (CSG) typically involves methods which have the potential to cause serious environmental impacts, such as the use of hydraulic fracturing, the use of a large number of toxic chemicals, and the extraction of large quantities of water from underground reserves.

Among the environmental risks posed by CSG are the contamination of surface and groundwater from methane and chemicals used in the extraction process, and the impacts to water systems from wastewater disposal.

CONTAMINATION OF GROUNDWATER AQUIFERS DUE TO ONSHORE GAS EXTRACTION

The potential for groundwater aquifers to be contaminated by methane as a result of onshore gas activity is a serious concern.[32] Gas can migrate vertically into overlying aquifers through fractures in the seams, or leak from well casings.[33] Numerous studies in the USA have confirmed methane contamination of drinking water aquifers in areas surrounding gas well operations, including at hazardous and potentially explosive levels.[34] These studies relate to the impacts of shale gas, and demonstrate the potential for onshore gas wells to act as a pathway for gas and chemical migration into aquifers.[35]

It is generally understood that there is a low likelihood of groundwater contamination from CSG, as groundwater is likely to flow into the CSG well rather than the reverse.[36] However, in Australia, bubbling methane gas has previously been observed and recorded in the Condamine River, which runs through the CSG fields of the Surat Basin in Queensland.[37] Queensland farmers have also reported methane contamination of bore water at levels which are flammable.[38] Moreover, recent studies in the Tara gas fields in Queensland have revealed evidence of large-scale seepage and leaking of methane.[39] Overall, data on this issue is limited, and the environmental and health impacts of methane require further investigation.[40]

RISKS FROM HYDRAULIC FRACTURING

Hydraulic Fracturing or 'fracking' is a technique used in the onshore gas drilling process to increase the amount of gas that can be extracted from the well. Fracking involves pumping large quantities of fluids at very high pressure into the coal seam in order to force open narrow fractures in the seam so gas will flow out when the water is extracted.[41] The fracking fluids contain chemical additives designed to facilitate the fracturing of the seam.[42]

There are serious risks that both ground and surface waters can be contaminated by the toxic chemicals contained in fracking and drilling fluids, with impacts on human and ecological health.[43] Few of the chemicals used in fracking have listed safe drinking water standards, and there is still much uncertainty about the potential environmental and toxic impacts of the chemicals used.[44]

The New South Wales and Queensland governments have both banned the use of 'BTEX'[45] chemicals in hydraulic fracturing due to concerns over the toxicity of these chemicals and their impacts to environment and health.[46] In 2013, the NSW government also announced regulations that banned gas wells within two kilometres of residential areas.[47] These Government moves are

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[32] Williams, J., Stubbs, T. & Milligan, A. (2012b) *An analysis of coal seam gas production and natural resource management in Australia: Issues and Ways Forward*, A report prepared for the Australian Council of Environmental Deans and Directors (ACEDD) by John Williams Scientific Services Pty Ltd, Canberra, Australia, at 50.

[33] National Water Commission (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra: http://www nwc.gov.au/__data/assets/pdf_file/0003/9723/Coal_Seam_Gas.pdf

[34] Jackson, R., Vengosh, A., Darrah, T., Warner, N., Down, A., Poreda, R., Osborn, S., Zhao, K., and Karr, J. (2013) Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences of the United States of America*, 2013, 110(28): 11250-11255; Warner, N., Jackson, R., Darrah, T., Osborn, S., Down, A., Zhao, K., Vengosh, A. (2012) Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences of the United States of America*, 2012, 109(30): 11961-11966; USEPA (2011) Draft Investigation of Groundwater Contamination near Pavillion, Wyoming. United States Environmental Protection Agency, December 2011; Osborn S., Vengosh A., Warner N., Jackson R. (2011) Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, 108(20): 8172-8176.

[35] New South Wales Chief Scientist and Engineer (2013) Initial report on the Independent Review of Coal Seam Gas Activities in NSW, Office of the New South Wales Chief Scientist and Engineer, 30 July 2013, at 69.

[36] Geoscience Australia & Dr Habermehl M.A. (2010) Summary Of Advice In Relation To The Potential Impacts Of Coal Seam Gas Extraction In The Surat And Bowen Basins, Queensland Phase One Report Summary For Australian Government Department Of Sustainability, Environment, Water, Population And Communities provided by Geoscience Australia and Dr M.A. Habermehl, Canberra, 29 September 2010; CSIRO (2012) Coal seam gas developments predicting impacts. Available at: http://www.csiro.au/news/coal-seam-gas.

[37] Australian Broadcasting Corporation (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.
A state government report investigating the incident did not find definitive evidence of the source or cause of the methane gas seeps. However, its investigation is continuing. See: Queensland Government Department of Natural Resources and Mines (2012) Summary Technical Report – Part 1: Condamine River Gas Seep Investigation. Queensland Government Department of Natural Resources and Mines, December 2012, Brisbane.

[38] Australian Broadcasting Corporation (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.

[39] Tait, D., Santos, I., Maher, D., Cyronak, T., and Davis, R. (2013) Enrichment of Radon and Carbon Dioxide in the Open Atmosphere of an Australian Coal Seam Gas Field, *Environmental Science & Technology* 2013, 47(7): 3099-3104; Santos, I., & Maher, D. (2012) Submission on National Greenhouse and Energy Reporting (Measurement) Determination 2012 – Fugitive Emissions from Coal Seam Gas. Submission to the Commonwealth Department of Climate Change and Energy Efficiency, October 2012.

[40] Jackson, R., Vengosh, A., Darrah, T., Warner, N., Down, A., Poreda, R., Osborn, S., Zhao, K., and Karr, J. (2013) **Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction.** *Proceedings of the National Academy of Sciences of the United States of America*, 2013, 110(28): 11250-11255; Tait, D., Santos, I., Maher, D., Cyronak, T., and Davis, R. (2013) Enrichment of Radon and Carbon Dioxide in the Open Atmosphere of an Australian Coal Seam Gas Field, *Environmental Science & Technology* 2013, 47(7): 3099-3104.

[41] Williams, J., Stubbs, T. & Milligan, A. (2013), at 4.

[42] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 6.

[43] Batley, G. & Kookana, R. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9: 425–428; Lloyd-Smith, & Senjen, (2011).

[44] Batley, G.E. & Kookana, R.S. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9, at 426; National Health and Medical Research Council and Natural Resource Management Ministerial Council (2011). Australian Drinking Water Guidelines: Paper 6, National Water Quality Management Strategy. National Health and Medical Research Council, and National Resource Management Ministerial Council, Commonwealth of Australia, Canberra. Available at: http://www nhmrc.gov.au/_files_nhmrcpublications/attachments/eh52_aust_drinking_water_guidelines_update_120710_0.pdf

[45] benzene, toluene, ethylbenzene, and xylene.

[46] New South Wales Chief Scientist and Engineer (2013) Initial report on the Independent Review of Coal Seam Gas Activities in NSW, Office of the New South Wales Chief Scientist and Engineer, 30 July 2013, at 66, 69; Leather, Bahadori, Nwaoha, and Wood (2013).

[47] NSW DPI (2014) Coal Seam Gas Exclusion Zones, New South Wales department of Planning and Infastructure, Sydney. Accessed via: http://www.planning nsw.gov.au/coal-seam-gas-exclusion-zones.

indicative of the critical concerns recognised in relation to onshore gas impacts on water. However, gas wells may still encroach as close as 200 metres away from a home or farm.[48]

The likelihood of groundwater contamination from fracking chemicals is deemed relatively low, since most of the fracking fluid (about 60-80%) is removed as 'flow back' or 'produced' water, and the underground layers between the coal seam and aquifers are of very low permeability.[49] However, uncertainty remains over the potential for fracking to open up connections between the layers, and farmers in Queensland have previously reported methane contamination of bore water at flammable levels.[50]

Furthermore, there are concerns about the chemical quality of the fracking product fluid and its effective disposal along with produced water.

### Risks posed by process wastewater

The extraction of CSG results in large quantities produced wastewater, which is generally highly saline and can contain fracking chemicals and other contaminants, like organic compounds from the coal seam.[51]

The question of how this wastewater can be disposed of safely is a critical issue, as the wastewater poses major contamination risks.[52] Yet, as Williams, Stubbs & Milligan observe, "storage, treatment and disposal of this water in ways that do not impact on the aquatic ecology and hydrology of the landscape remain, to a large extent, an unsolved problem"[53].

Therefore, produced water must be treated before it can be safely disposed of.[54] However, water treatment generally involves desalination by reverse osmosis, which cannot remove all the chemicals and contaminants.[55]

### Discharge into surface waters

In some instances, produced wastewater is treated and discharged into nearby rivers and streams.[56] The National Water Commission has stated that this could alter natural water flow patterns and have significant impacts on water quality, damaging the ecological health of affected surface-water systems.[57] The Water Group has also expressed concern to the federal government about the impacts to surface water systems from this discharge.[58] Water quality could be impacted in a variety of ways, including: turbidity, temperature, oxygen content, and nutrient content.[59]

In the Pilliga, near Narrabri in Northwest New South Wales, where treated water was discharged into the Bohena Creek, water sampling of the Creek found elevated levels of methane, cyanide, boron, bromide, lithium, and ammonia.[60] A subsequent biodiversity survey linked the pollution of streams in the Pilliga from produced water discharge to the deaths of local aquatic species.[61] In the United States, the contamination of surface waters in areas of shale gas operations have also been documented, as have impacts to the health of both wildlife and humans.[62] However, there are still serious information gaps when it comes to the chemical content of produced water and the impacts of such water contamination on local ecosystems remain largely unknown.[63]

### Reinjection of Waste Water Underground

The reinjection of treated wastewater from the coal seam into the aquifer is another potential disposal method. This approach to wastewater management is favoured by the Queensland government because of its potential to 'make good' on drawdown or damage to aquifers supplying agricultural and local water users.[64] Theoretically, reinjection will assist in maintaining the water

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[48] *Onshore Petroleum Act 1991* (NSW), section 72.
[49] Geoscience Australia & Dr Habermehl M.A. (2010) Summary Of Advice In Relation To The Potential Impacts Of Coal Seam Gas Extraction In The Surat And Bowen Basins, Queensland Phase One Report Summary For Australian Government Department Of Sustainability, Environment, Water, Population And Communities provided by Geoscience Australia and Dr M.A. Habermehl, Canberra, 29 September 2010; CSIRO (2012) Coal seam gas developments predicting impacts. Available at: http://www.csiro.au/news/coal-seam-gas.
[50] Australian Broadcasting Corporation (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.
[51] Williams, Stubbs, & Milligan (2012b), at 48; Lloyd-Smith, & Senjen (2011), at 10.
[52] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011; Nghiem L., Ren, T., Aziz, N., Porter, I. and Regmi, G. (2011) Treatment of coal seam gas produced water for beneficial use in Australia: A review of best practices. *Desalination and Water Treatment* 32: 316-323; Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012.
[53] Williams, Stubbs, & Milligan (2012b), at 49.
[54] Lloyd-Smith, & Senjen (2011), at 16.
[55] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 16; Khan, S.J. (2010) Quantitative chemical exposure assessment for water recycling schemes, Waterlines Report Series No 27, Report commissioned by the National Water Commission, March 2010. See also: A. Bbdalo-Santoyo, J.L. Gbmez-Carrasco, E. Gbmez-Gbmez, M.F. Maximo-Martin, A.M. Hidalgo-Montesinos (2004) Spiral-wound membrane reverse osmosis and the treatment of industrial effluents. *Desalination* 160: 151-158.
[56] Williams, Stubbs, & Milligan (2012b), at 49.
[57] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra; RPS Australia (2011), 'Onshore co-produced water: extent and management', *Waterlines Report Series no 54, September 2011*, National Water Commission, Canberra; NWC (2012) Coal seam gas update—June 2012, National Water Commission, Canberra. Accessed via: http://nwc.gov.au/nwi/position-statements/coal-seam-gas.
[58] WG (2010) Water Group Advice On EPBC Act Referrals Referral - 2008/4399 Santos-Petronas Referral - 2008/4059 And Comments On Ap Lng Referral - 2009/4974, Based On Information Provided By The Proponents To Close Of Business 03/09/10, Water Group, September 2010, at 12.
[59] Williams, Stubbs, & Milligan (2012b), at 49.
[60] Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012, at 29-32.
[61] Milledge, D. (2012) National Significance: the ecological values of Pilliga East
Forest and the threats posed by coal seam gas mining 2011-2012. A report prepared for the Northern Inland Council for the Environment and the Coonabarabran and Upper Castlereagh Catchment and Landcare Group, 2012.
[62] Bamberger M. & Oswald R. (2012) Impacts of Gas Drilling on Human and Animal Health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 2012: 51-77.
It is worth noting, however, that this paper has limitations in data and recommends further research to confirm the correlations between chemicals and impacts.
[63] New South Wales Legislative Council (2012) Coal Seam Gas. New South Wales Parliament Legislative Council, General Purpose Standing Committee No.5, Inquiry into coal seam gas, May 2012, Sydney, NSW: at 30.
[64] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, Commonwealth of Australia Department of the Senate, November 2011, Canberra, at 25-26, 42-43. See: Queensland Department of Environment and Resource Management (2012) Coal Seam Gas Water Management Policy. Queensland Government, Department of Environment and Resource Management, December 2012.

balance in a given area.[65] Yet, despite the stated potential of reinjection, "at this stage its feasibility is not proven"[66].

Evidence provided to the Commonwealth Senate Inquiry into CSG impacts on the Murray-Darling Basin suggests that reinjection is far from a solution to wastewater management issues, as while it is technically feasible, it is unlikely to be possible in most cases.[67]

It is worth noting the concerns raised above by the National Toxics Network and others about the limitations of wastewater treatment by reverse osmosis and the potential toxicity of fracking chemicals, since all water reinjected into aquifers used for human consumption or agriculture must adhere to Australian Drinking Water Standards.[68] Where reinjection is alternatively used to dispose of brine or highly saline wastewater back into the coal seam, there must also be assurances that the seam is at a depth and of a stability to ensure that there is no risk of cross contamination of aquifers.[69] Doing so "is both expensive and technically demanding"[70].

[65] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 42.
[66] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 26.
[67] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 42-43.
[68] Batley, G.E. & Kookana, R.S. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9, at 426; Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 16; Nghiem L., Ren, T., Aziz, N., Porter, I. and Regmi, G. (2011) Treatment of coal seam gas produced water for beneficial use in Australia: A review of best practices. *Desalination and Water Treatment* 32: 316-323; Khan, S.J. (2010) Quantitative chemical exposure assessment for water recycling schemes, Waterlines Report Series No 27, Report commissioned by the National Water Commission, March 2010; A. Bbdalo-Santoyo, J. Gbmez-Carrasco, E. Gbmez-Gbmez, M. Maximo-Martin, A. Hidalgo-Montesinos (2004) Spiral-wound membrane reverse osmosis and the treatment of industrial effluents. *Desalination* 160: 151-158; National Health and Medical Research Council and Natural Resource Management Ministerial Council (2011) Australian Drinking Water Guidelines: Paper 6, National Water Quality Management Strategy. National Health and Medical Research Council, and National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.
[69] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 43.
[70] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 43.

## RISKS TO ECOLOGY

Onshore gas production, like other land-uses, "poses risks to the condition of nearby water, soil, vegetation and biodiversity."[71]

There are a number of potential ecological impacts from CSG.[72] These include:

- Loss of biodiversity through fragmentation of habitat and native vegetation clearing.
- Introduction of invasive species and increased predation of native species.
- Increased bushfire risk.
- Sedimentation and erosion.
- Water and soil contamination from produced chemical wastewater, through leaks and spills.

### FRAGMENTATION OF HABITAT AND NATIVE VEGETATION

By its scale and nature, the surface 'footprint' of a CSG-production field cuts through the landscape and natural habitat.

In Australia, the average density of a CSG production field is approximately 1.1 well pads and 1.6 kilometres of road per square kilometre of land,[73] but well pads can be placed as close as 200 metres apart.[74]

This surface infrastructure and its connecting roads can cause significant fragmentation to surface ecology, as it requires the clearing of large areas of land.[75]

The development of CSG infrastructure involves the direct removal of native vegetation in order to allow access, clear a firebreak and produce a workspace around the drilling site.[76]

This land clearing can lead to the introduction of invasive species (especially weeds) and cut into the habitat and breeding areas of native fauna.[77] The negative impacts of such bushland fragmentation on native fauna have been demonstrated in a number of scientific studies.[78]

Moreover, in areas where the landscape has already been partly cleared for agriculture, transport corridors, or regional settlement, the natural vegetation and habitat that remains may be of a high ecological value.[79] This means that the addition of CSG developments to the landscape would carry added, heightened risks of damaging ecological impact.[80]

The Water Group, in its 2010 advisory report to the Australian Government, found that CSG operations were likely to have significant impacts on 'Matters of National Environmental Significance' listed under federal government legislation, such as Threatened Ecological Communities.[81]

Where there is a specific danger to threatened native species posed by CSG development, then the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) should apply. However, as Williams, Stubbs & Milligan note, the provisions of the EPBC Act "do not easily deal with broad-scale fragmentation and cumulative loss of habitat".[82]

### RISKS OF SOIL CONTAMINATION

The contamination of soils by chemicals, salt wastewater, and methane can occur as a result of onshore gas operations. This can be due to inappropriate wastewater disposal; spills and leaks of produced wastewater, fracking fluids or drilling fluids; and the seepage of methane into soils.[83]

Hydraulic fracturing or 'fracking' is a technique used in the onshore gas drilling process to increase the amount of gas that can be extracted from the well. Fracking involves pumping large quantities of fluids at very high pressure into the coal seam in order to force open narrow fractures in the seam so gas will flow out when the water is extracted.[84] The fracking fluids contain chemical

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[71] Williams J., Stubbs T. & Milligan A. (2012a) Some ways forward for coal seam gas and natural resource management in Australia. An outline of the report 'An analysis of coal seam gas production and natural resource management in Australia: Issues and ways forward' prepared for the Australian Council of Environmental Deans and Directors by John Williams Scientific Services Pty Ltd, Canberra, Australia. October 2012, at 3.

[72] Batley, G. & Kookana, R. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9: 425–428; CSIRO (2012) Coal seam gas developments—predicting impacts, April 2012; NWC (2012) Coal seam gas update—June 2012, National Water Commission, Canberra: http://nwc.gov.au/nwi/position-statements/coal-seam-gas; Williams, J., Stubbs, T. & Milligan, A. (2012b) *An analysis of coal seam gas production and natural resource management in Australia: Issues and Ways Forward*, A report prepared for the Australian Council of Environmental Deans and Directors (ACEDD) by John Williams Scientific Services Pty Ltd, Canberra, Australia; Randall, A. (2012) Coal seam gas—toward a risk management framework for a novel intervention, *Environmental and Planning Law Journal* 29(2): 152–162.

[73] Eco Logical Australia (2012) Assessing the cumulative risk of mining scenarios on bioregional assets in the Namoi Catchment: development and trial of an interactive GIS tool, Prepared for the Namoi Catchment Management Authority, New South Wales.

[74] Williams, Stubbs, & Milligan (2012b), at 32.

[75] Williams, Stubbs, & Milligan (2012b), at 2-3, 32-33.

[76] Williams, J., Stubbs, T. & Milligan, A. (2013) Coal Seam Gas Production: Challenges and Opportunities, report to the Bureau of Resources and Energy Economics, Canberra, at 7.

[77] Williams, Stubbs, & Milligan (2013), at 7.

[78] See, for example, Wiens, J.A. (1985) Vertebrate responses to environmental patchiness in arid and semiarid ecosystems, In: Pickett, S.T.A. & White, P.S. (eds.) *The ecology of natural disturbances and patch dynamics*, Academic Press, New York, pp. 169–193; Forman, R.T.T. & Gordon, M. (1986) *Landscape Ecology*, John Wiley & Sons: New York; Franklin, J.F. & Forman, R.T. (1987) Creating landscape patterns by forest cutting: ecological consequences and principles, *Landscape Ecology* 1, 5–18; Saunders, D.A., Hobbs, R.J. & Margules, C.R. (1991) Biological consequences of ecosystem fragmentation: a review, *Conservation Biology* 5, 18–32; Ries, L., Fletcher Jr, R.J., Battin, J. & Sisk, T.D. (2004) Ecological responses to habitat edges: mechanisms, models, and variability explained, *Annual Review of Ecology Evolution and Systematics* 35, 491–522; Fischer, J. & Lindenmayer, D.B. (2007) Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* 16, 265–280.

[79] Fischer, J. & Lindenmayer, D.B. (2007) Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* 16, 265–280; Hansen, M.J. & Clevenger, A.P. (2005) The influence of disturbance and habitat on the presence of non-native plant species along transport corridors, *Biological Conservation* 125, 249–259.

[80] See, for example: Gillen, J. & Kiviat, E. (2012) Hydraulic fracturing threats to species with restricted geographic ranges in the eastern United States. *Environmental Practice* 14: 320–331.

[81] WG (2010) Water Group Advice On EPBC Act Referrals Referral - 2008/4399 Santos-Petronas Referral - 2008/4059 And Comments On Ap Lng Referral - 2009/4974, Based On Information Provided By The Proponents To Close Of Business 03/09/10, Water Group, September 2010, at 5-7.

[82] Williams, Stubbs, & Milligan (2013), at 8.

[83] Atkinson, C. (2005) Coal Bed Methane Hazards in New South Wales. Report prepared for Tony Davis & Associates, Australian Gas Alliance, New South Wales, January 2005; Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012.

[84] Williams, J., Stubbs, T. & Milligan, A. (2013), at 4.

additives designed to facilitate the fracturing of the seam.[85] There is still much uncertainty about the potential environmental and toxic impacts of the chemical used.[86]

The onshore extraction of gas results in large quantities produced wastewater, which is generally highly saline and can contain fracking chemicals and other contaminants, like organic compounds from the coal seam.[87]

The question of how this wastewater can be disposed of safely is a critical issue, as the wastewater poses major contamination risks.[88] Yet, as Williams, Stubbs & Milligan observe, "storage, treatment and disposal of this water in ways that do not impact on the aquatic ecology and hydrology of the landscape remain, to a large extent, an unsolved problem"[89].

Therefore, produced wastewater must be treated before it can be safely disposed of.[90] However, water treatment generally involves desalination by reverse osmosis, which cannot remove all the chemicals and contaminants.[91]

The treatment of produced wastewater also results in considerable quantities of salt concentrate that will require disposal, as the average CSG well produces around 100 kilograms of salt per day.[92] The disposal of salt is another significant issue which is yet to be resolved.[93] Some CSG companies have considered disposing of the salt at sea or transporting it to a waste facility. However, "these options would require a large fleet of tankers operating 24 hours a day"[94]. As such, these options have been ruled out on environmental and economic grounds.[95]

Historically, evaporations ponds have been used throughout the gas fields to store wastewater.[96] Evaporation ponds were assessed by the Queensland Government as posing substantial environmental risks due to high susceptibility to flooding and spills and the likelihood of soil contamination from salts and other chemicals.[97] While the practice of evaporation ponds is now banned in both New South Wales and Queensland, "largely because of seepage into soils"[98], the storage of produced wastewater and salt in 'holding ponds' continues as a temporary solution. Nevertheless, "a long-term storage pond can be an evaporation pond in all but name"[99].

In Australia, there have been several reported incidents of storage ponds leaking or overflowing, with soil contamination, vegetation dieback and animal deaths recorded in the surrounding areas.[100] In the United States, soil contamination and impacts to wildlife have also been documented in areas of shale gas operations.[101]

### LAND SUBSIDENCE

The process of 'dewatering', and the associated changes to underground water pressure, has been demonstrated to generally result in minor subsidence, or sinking, of land on the surface.[102]

Moran and Vink, in their 2010 study for the Australian Government, noted the ecological risks of land subsidence as a result of CSG production, stating that:

> "*...even small changes to the land surface due to subsidence may alter overland flow paths initiating new erosion features in susceptible areas. Additionally, subsidence may also change or cause fracturing in aquifers which may alter the hydraulic connectivity.*"[103]

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[85] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 6.
[86] Batley, G.E. & Kookana, R.S. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9, at 426.
[87] Williams, Stubbs, & Milligan (2012b), at 48; Lloyd-Smith, & Senjen (2011), at 10.
[88] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011; Nghiem L., Ren, T., Aziz, N., Porter, I. and Regmi, G. (2011) Treatment of coal seam gas produced water for beneficial use in Australia: A review of best practices. *Desalination and Water Treatment* 32: 316-323; Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012.
[89] Williams, Stubbs, & Milligan (2012b), at 49.
[90] Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 16.
[91] Lloyd-Smith & Senjen (2011), at 16; Khan, S.J. (2010) Quantitative chemical exposure assessment for water recycling schemes, Waterlines Report Series No 27, Report commissioned by the National Water Commission, March 2010. See also: A. Bbdalo-Santoyo, J.L. Gbmez-Carrasco, E. Gbmez-Gbmez, M.F. Maximo-Martin, A.M. Hidalgo-Montesinos (2004) Spiral-wound membrane reverse osmosis and the treatment of industrial effluents. *Desalination* 160: 151-158.
[92] Williams, Stubbs, & Milligan (2012b), at 49; Nghiem L., Ren, T., Aziz, N., Porter, I. and Regmi, G. (2011) Treatment of coal seam gas produced water for beneficial use in Australia: A review of best practices. *Desalination and Water Treatment* 32: 316-323.
[93] Khan, S. and Kordek, G. (2013) Coal Seam Gas: Produced Water and Solids, Report Prepared for the Office of the New South Wales Chief Scientist and Engineer, November 2013.
[94] Williams, Stubbs, & Milligan (2012b), at 50.
[95] Williams, Stubbs, & Milligan (2012b), at 50.
[96] Nghiem L., Ren, T., Aziz, N., Porter, I. and Regmi, G. (2011) Treatment of coal seam gas produced water for beneficial use in Australia: A review of best practices. *Desalination and Water Treatment* 32: 316-323.
[97] Queensland Department of Environment and Resource Management (DERM) (2010) Coal Seam Gas Water Management Policy. Queensland Government, Department of Environment and Resource Managemennt, June 2010; Queensland Department of Infrastructure and Planning (DIP) (2009) CSG water discussion paper. *Queensland Government, Department of Infrastructure and Planning*, May *2009.*
[98] Batley, G.E. & Kookana, R.S. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, Environmental Chemistry 9, at 426.
[99] SCRAT (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, November 2011, Senate Standing Committee on Rural Affairs & Transport, Canberra, at 41.
[100] Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012.
[101] Bamberger M. & Oswald R. (2012) Impacts of Gas Drilling on Human and Animal Health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 2012: 51-77.
It is worth noting, however, that this paper has limitations in data and recommends further research to confirm the correlations between chemicals and impacts.
[102] Williams, Stubbs, & Milligan (2012b), at 53.
[103] Moran, C. & Vink, S. (2010) Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin, Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland, at 4.

**IMPACTS ON AGRICULTURE**

Onshore gas production "has to be seen as a new land use competing with other land uses in a region"[104]. As such, the co-existence of onshore gas operations with cropping, grazing and other forms of agricultural production "is a vexed issue"[105].

**LAND USE**

By its scale and nature, the surface 'footprint' of a CSG-production field cuts through the landscape. In Australia, the average density of a CSG production field is approximately 1.1 well pads and 1.6 kilometres of road per square kilometre of land,[106] and well pads can be placed as close as 200 metres apart.[107]

This surface infrastructure and its connecting roads require the clearing of large areas of land, and can cause significant disruption to other activities such as agricultural production.[108] Indeed, as the Report of the Commonwealth Senate Committee on the impacts of CSG in the Murray-Darling Basin notes: "Exploration for, or production of, gas has the potential to severely disrupt virtually every aspect of agricultural production on cropping lands and, in extreme circumstances, remove the land from production."[109]

Under Australian law, minerals under the earth's surface belong to the Crown, represented by the states. The right to explore for and produce gas is granted by the state to gas companies. As such, a landholder who does not wish to have CSG activity on their land has no legal right to stop a CSG company from gaining land access.[110] Where a landowner refuses gas operations on their land, the gas company can require the landholder to enter into arbitration and force them to comply with the legal outcome, including the granting of access to the land.[111]

When it comes to dealing with landowner disputes around access, the traditional approach of large open-cut mining operations has been for the mining company to purchase the land at valuations well above commercial value.[112] However, for CSG, the irregular distribution and spacing of wells makes total acquisition of properties impractical.[113] Property holders must therefore deal with the nuisances of noise and access, as well as the potential impacts of gas development to their overall property value.[114]

LOCAL POLLUTION FROM ONSHORE GAS OPERATIONS

Air, dust, light and noise pollution can come from onshore gas operations such as drilling and pumping engines, diesel generators, and heavy vehicle use.[115] The air pollution and chemicals from these operations could pose serious risks to human and animal health.[116]

A recent Australian study of the Tara CSG fields in Queensland found high local atmospheric concentrations of radon, a gas linked to negative health impacts.[117] The study also found that these elevated levels strongly correlated with the number of gas wells in the area.[118]

Residents near the CSG fields in Tara have for years been reporting health complaints that could be linked to methane leakage.[119] An investigation by the Queensland Government Department of Health was unable to verify any links between these health complaints and CSG, citing the lack of baseline data and ongoing scientific monitoring concerning CSG operations.[120] As a result of the study, the Queensland Health Department recommended the introduction of stricter CSG monitoring programs to watch and prevent any unsafe community exposure.[121]

GROUNDWATER

The gas drilling and fracking processes require considerable amount of water, which means gas companies also compete with local landholders and agricultural producers for water supplies.[122]

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[104] Williams, Stubbs, & Milligan, (2012b) *An analysis of coal seam gas production and natural resource management in Australia: Issues and Ways Forward*, A report prepared for the Australian Council of Environmental Deans and Directors (ACEDD) by John Williams Scientific Services Pty Ltd, Canberra, Australia, at 35.

[105] Williams J., Stubbs T. & Milligan A. (2012a) Some ways forward for coal seam gas and natural resource management in Australia. An outline of the report 'An analysis of coal seam gas production and natural resource management in Australia: Issues and ways forward' prepared for the Australian Council of Environmental Deans and Directors by John Williams Scientific Services Pty Ltd, Canberra, Australia. October 2012, at 6.

[106] Eco Logical Australia (2012) Assessing the cumulative risk of mining scenarios on bioregional assets in the Namoi Catchment: development and trial of an interactive GIS tool, Prepared for the Namoi Catchment Management Authority, New South Wales.

[107] Williams, Stubbs, & Milligan (2012b), at 32.

[108] Williams, Stubbs, & Milligan (2012b), at 2-3, 32-33.

[109] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, Commonwealth of Australia Department of the Senate, November 2011, Canberra, at 62.

[110] New South Wales Chief Scientist and Engineer (2013) Initial report on the Independent Review of Coal Seam Gas Activities in NSW, Office of the New South Wales Chief Scientist and Engineer, 30 July 2013, at 30.

[111] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, Commonwealth of Australia Department of the Senate, November 2011, Canberra, Chapter 4: Land Access and Land Use, at 53.

[112] Williams, J., Stubbs, T. & Milligan, A. (2013) Coal Seam Gas Production: Challenges and Opportunities, report to the Bureau of Resources and Energy Economics, Canberra, at 9.

[113] Williams, J., Stubbs, T. & Milligan, A. (2013), at 9.

[114] Poisel, T. (2012) Coal seam gas exploration and production in New South Wales: the case for better strategic planning and more stringent regulation, *Environmental and Planning Law Journal* 29(2): 129–151; Swayne, N. (2012) Regulating coal seam gas in Queensland: lessons in an adaptive environmental management approach? *Environmental and Planning Law Journal* 29(2): 163–183; Lloyd, D., Luke, H. & Boyd, W. (2013) Community perspectives of natural resource extraction: coal-seam gas mining and social identity in Eastern Australia, *Coolabah* 10: 144–164.

[115] Williams, Stubbs, & Milligan, (2012b), at 40.

[116] McKenzie, L., Witter, R., Newman, L., Adgate, J. (2012) Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of the Total Environment* 424 (May 2012): 79–87; Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011; Bamberger M. & Oswald R. (2012) Impacts of Gas Drilling on Human and Animal Health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 2012: 51-77.

[117] Tait, D., Santos, I., Maher, D., Cyronak, T., and Davis, R. (2013) Enrichment of Radon and Carbon Dioxide in the Open Atmosphere of an Australian Coal Seam Gas Field, *Environmental Science & Technology* 2013, 47(7): 3099-3104.

[118] Tait, Santos, Maher, Cyronak, and Davis, (2013).

[119] Queensland Department of Health (2013) Coal Seam Gas in the Tara Region: Summary Risk Assessment of Health Complaints and Environmental Monitoring Data. Queensland Government, Department of Health, March 2013.

[120] Queensland Department of Health (2013), at 18.

[121] Queensland Department of Health (2013), at 18-19.

[122] Williams, J., Stubbs, T. & Milligan, A. (2012b), at 48.

There is an obvious risk that the extraction of large volumes of groundwater from the coal seams and resulting changes in pressures may lower water tables and reduce the water resources available in connected surface-waters and groundwater systems.[123]

This is of particular concern for Australian agricultural producers, because most major gas operations occur in areas where water resources are already stressed.[124] Some of those systems, such as the Great Artesian Basin and the Murray-Darling Basin may already be fully or over-allocated.[125] This can have negative impacts for other water users and the local environment.[126]

The most likely impacts are the loss of pressure in a landholder's bore or the lowering of the water table to such an extent that the bore no longer produces water.[127] A 2012 study by the Queensland Water Commission also found a definitive link between bore water levels and coal seam gas operations.[128] The Underground Water Impact Report identified 85 wells in Queensland at risk of running out of water supply within 3 years, and a further 528 wells that are likely to be similarly impacted by CSG operations in the long-term.[129]

Queensland farmers have also reported methane contamination of bore water at levels which are flammable.[130]

In Queensland, where there is proven impact from local CSG operations on an adjacent landholder's water supply, the company is required to 'make good' on that damage.[131] "Make good options range from the relatively straight forward to the complex and unproven."[132]

The simplest responses will be to deepen existing bores or sink new bores.[133] Some CSG companies may also seek to provide the landholder with treated water from the company's own storage ponds to supplement or replace the impacted supply.[134]

However, there are concerns over the salt content and quality of treated CSG wastewater, and uncertainties remain as to whether CSG companies can effectively replace the water lost.[135] Although Queensland's make good obligations theoretically extend beyond the life of CSG operations, it is also unclear as to how CSG companies can mitigate the long-term and cumulative impacts of dewatering.[136]

In some cases, providing 'alternative compensation' may be necessary,[137] as without a long-term reliable water supply, a farmer's property may cease to be viable. Yet the prospect of compensation at a price reflecting the pre-CSG value of the property and the loss of livelihood seems unlikely.[138]

RISKS FROM HYDRAULIC FRACTURING

There are serious risks that both land and water can be contaminated by the toxic chemicals contained in fracking and drilling fluids, with impacts on human, animal and ecological health.[139] For example, in the United States, the spill of fracking fluid into a cow pasture was directly linked to the immediate deaths of 17 livestock.[140] In another case, livestock exposed to toxic chemicals present in the soil of land contaminated by fracking wastewater suffered from reproductive problems, producing stillborn and stunted calves.[141] Similarly, in Australia, there have been several reported incidents of storage ponds leaking or overflowing, with soil contamination, vegetation dieback and animal deaths recorded in the surrounding areas.[142]

Few of the chemicals used in fracking have listed safe drinking water standards, and there is still much uncertainty about the potential environmental and toxic impacts of the chemicals used.[143]

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[123] Williams, Stubbs & Milligan (2012b), at 42; Nelson, R. (2012) Unconventional Gas and Produced Water. In: *Australia's Unconventional Energy Options*, A report commissioned by the Committee for Economic Development in Australia, September 2012, Melbourne, at 30; Hillier, J. (2010) Groundwater Connections Between the Walloon Coal Measures and the Alluvium of the Condamine River. A report for the Central Downs Irrigators Ltd, August 2010.
[124] RPS Australia (2011), 'Onshore co-produced water: extent and management', *Waterlines Report Series no 54, September 2011*, National Water Commission, Canberra, *at 33.*
[125] NWC (2011) Position Statement—Coal seam gas and water, National Water Commission, Canberra, at 1.
http://www nwc.gov.au/__data/assets/pdf_file/0003/9723/Coal_Seam_Gas.pdf
[126] Nelson, R. (2012) Unconventional Gas and Produced Water. In: *Australia's Unconventional Energy Options*, A report commissioned by the Committee for Economic Development in Australia, September 2012, Melbourne, at 30.
[127] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, Commonwealth of Australia Department of the Senate, November 2011, Canberra, at 25.
[128] Queensland Water Commission (2012) Underground Water Impact Report for the Surat Cumulative Management Area. Office of Groundwater Impact Assessment, Queensland Government Department of Natural Resources and Mines, July 2012, Brisbane: http://dnrm.qld.gov.au/__data/assets/pdf_file/0016/31327/underground-water-impact-report.pdf
[129] Queensland Water Commission (2012), at x-xii, 53-58.
[130] Australian Broadcasting Corporation (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.
[131] *Water Act 2000* (Qld) s.376(b)(iv), 387, 409, 421, Ch. 3 Pt. 5.
[132] Commonwealth Senate Standing Committee on Rural Affairs & Transport (SCRAT) (2011) The impact of mining coal seam gas on the management of the Murray Darling Basin, Commonwealth of Australia Department of the Senate, November 2011, Canberra, at 25.
[133] Commonwealth Senate Standing Committee on Rural Affairs & Transport (2011), at 25.
[134] SCRAT (2011), at 25.
[135] Batley, G. & Kookana, R. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9: 425–428; Lloyd-Smith, M., & Senjen, R. (2011) Hydraulic Fracturing in Coal Seam Gas Mining: The risks to our health, communities, environment and climate. Briefing paper prepared for the National Toxics Network, September 2011, at 6; Australian Broadcasting Corporation (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.
[136] Nelson, R. (2012) Unconventional Gas and Produced Water. In: *Australia's Unconventional Energy Options*, A report commissioned by the Committee for Economic Development in Australia, September 2012, Melbourne, at 37.
[137] SCRAT (2011), at 26; Nelson, R. (2012), at 37.
[138] SCRAT (2011), at 26.
[139] Batley, G. & Kookana, R. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9: 425–428; Lloyd-Smith, & Senjen, (2011).
[140] Bamberger M. & Oswald R. (2012) Impacts of Gas Drilling on Human and Animal Health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 2012: at 59.
It is worth noting, however, that this paper has limitations in data and recommends further research to confirm the correlations between chemicals and impacts.
[141] Bamberger M. & Oswald R. (2012) Impacts of Gas Drilling on Human and Animal Health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 2012: at 59-60.
[142] Flint, C. and Hogan, N. (2012) The truth spills out: A case study of coal seam gas exploration in the Pilliga, A report for the Northern Inland Council for the Environment, May 2012.
[143] Batley, G.E. & Kookana, R.S. (2012) Environmental issues associated with coal seam gas recovery: managing the fracking boom, *Environmental Chemistry* 9, at 426; National Health and Medical Research Council and Natural Resource Management Ministerial Council (2011). Australian Drinking Water Guidelines: Paper 6, National Water Quality

- IRRIGATION

Where reinjection of CSG wastewater underground is not a feasible option, gas companies have explored the potential for other forms of wastewater disposal. 'Virtual reinjection' includes the use of treated wastewater for agriculture, irrigation, and livestock watering. The industry considers these to be 'beneficial use' options, because they can replace some of the water lost from aquifers through CSG extraction.[144] However, the use of virtual reinjection is controversial, as "superficially this is an attractive option but it carries with it a range of problems."[145]

For water to be reinjected for direct use in agriculture, it must be treated to sufficient quality, carefully monitored and regulated.[146] However, as outlined above, there are serious doubts as to whether produced wastewater can be treated to sufficient quality.[147] Without a significant reduction in the salinity and sodium levels in the treated water, irrigation could cause irreversible impacts to crops and soil.[148] For example, in the United States' Powder River Basin, the use of treated produced water for irrigation in some soils resulted in a range of adverse impacts to the ecology, chemistry and hydrology of soils.[149] In Australia, where the existing salinity levels in soils can be quite high, the use of treated wastewater with even minor salt concentrations may have significant long-term impacts.[150] Such impacts could include: soil erosion, reduction in crop water intake, increased surface runoff, the development of clay surface seals, and the reduction of hydraulic conductivity in the soil.[151]

In its April 2013 report on environmental factors for the AGL Energy irrigation project in Gloucester, the NSW Environmental Protection Agency (EPA) raised serious concerns about the disposal of CSG wastewater through irrigation. The EPA advised the Department of Trade and Infrastructure that the irrigation project would lead to dangerously high salt levels and the potential destruction of farmland.[152] The Report also pointed to the lack of baseline information provided by the gas company as a factor which undermined and restricted the adequate assessment of impacts from the program.[153]

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**RISKS OF WELL FAILURE IN ONSHORE GAS EXPLORATION AND PRODUCTION**

The leakage of methane gas and toxic chemicals from onshore gas wells into aquifers or the air is a very strong concern of the community.[154] Gas wells are a potential channel for gas migration and linkage between the coal seam and aquifers, particularly in the long-term where abandoned wells degrade over time.[155] However, as the Commonwealth Senate Inquiry into the impacts of CSG in the Murray-Darling Basin has acknowledged, this issue has not received much attention in Australia.[156]

WELL INTEGRITY

Well integrity refers to the durability and solidity of the cement casing that lines the gas well.[157] If the cement shrinks, cracks or corrodes over time, this creates a heightened risk of water contamination and/or air pollution.[158] Methane, chemicals and fluids could leak out of the well and into the surrounding strata, making their way into nearby groundwater or the air above the surface.[159]

WATER CONTAMINATION FROM FLUID AND GAS MIGRATION

The potential for groundwater aquifers to be contaminated by methane as a result of onshore gas activity is a serious concern.[160] Gas can migrate vertically into overlying aquifers through leaks in well casings, as well as fractures and pores in the strata.[161] Numerous studies in the USA have confirmed methane contamination of drinking water aquifers in areas surrounding gas well operations, including at hazardous and potentially explosive levels.[162] While these studies relate to the impacts of shale gas, they appear to demonstrate the potential for gas wells to act as a pathway for gas and chemical migration into aquifers.[163]

In Australia, bubbling methane gas has previously been observed and recorded in the Condamine River, which runs through the CSG fields of the Surat Basin in Queensland.[164] Queensland farmers have also reported methane contamination of bore water at levels which are flammable.[165] Recent studies in the Tara gas fields in Queensland have revealed evidence of large-scale seepage and leaking of methane.[166] Overall, though, data on this issue is limited and the environmental and health impacts of methane require further investigation.[167]

Some gas industry sources have previously asserted that the methane contamination occurring in rivers and groundwater bores is 'naturally occuring', and thus unrelated to gas well drilling and fracking operations.[168] However, as well-casing expert Professor Anthony Ingraffea highlights, such claims fail to distinguish between hazardous or dangerous levels of methane in water and negligible levels which are not a source of concern.[169] Furthermore, such claims ignore the actual probabilities of dangerous 'natural' levels of methane in drinking water. Moreover, it ignores any timeline or concurrence issue – that is, the question of whether there has been any significant change in the concentration of methane concurrent with the beginning of any nearby gas field development.[170] Baseline studies do not suggest that dangerous levels of methane can occur naturally in groundwater.[171] As such, there exists a strong implication that gas drilling and fracking is the intervening factor causing elevated methane levels, where such elevated levels are recorded.[172]

AIR POLLUTION FROM GAS MIGRATION

Well integrity is also required to minimise the leakage of methane and other gases into the surrounding atmosphere,[173] as such pollution from gas operations could pose serious risks to human and animal health.[174]

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[163] New South Wales Chief Scientist and Engineer (2013) Initial report on the Independent Review of Coal Seam Gas Activities in NSW, Office of the New South Wales Chief Scientist and Engineer, 30 July 2013, at 69.

[164] Australian Broadcasting Corporation (ABC) (2013) *Gas Leak!* Four Corners, report by Matthew Carney and Connie Agius, 1 April 2013. Available at: http://www.abc net.au/4corners/stories/2013/04/01/3725150 htm.
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[166] Tait, D., Santos, I., Maher, D., Cyronak, T., and Davis, R. (2013) Enrichment of Radon and Carbon Dioxide in the Open Atmosphere of an Australian Coal Seam Gas Field, *Environmental Science & Technology* 2013, 47(7): 3099-3104; Santos, I., & Maher, D. (2012) Submission on National Greenhouse and Energy Reporting (Measurement) Determination 2012 – Fugitive Emissions from Coal Seam Gas. Submission to the Commonwealth Department of Climate Change and Energy Efficiency, October 2012.

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[170] Ingraffea, A. (2012), at 5.

[171] Ingraffea, A. (2012), at 5.

[172] Ingraffea, A. (2012), at 5.

[173] Williams, Stubbs, & Milligan (2013), at 4.

A recent Australian study of the Tara CSG fields in Queensland found high local atmospheric concentrations of radon, a gas linked to negative health impacts.[175] The study also found that these elevated levels strongly correlated with the number of gas wells in the area.[176]

Residents near the CSG fields in Tara have for years been reporting health complaints that could be linked to methane leakage.[177] An investigation by the Queensland Government Department of Health was unable to verify any links between these health complaints and CSG, citing the lack of baseline data and ongoing scientific monitoring of CSG operations.[178] As a result of the study, the Queensland Health Department recommended the introduction of stricter CSG monitoring programs to watch and prevent any unsafe community exposure.[179]

THE LIKELIHOOD OF WELL FAILURE

To avoid the impacts of water contamination or air pollution, wells must remain completely sealed into the indefinite future.[180] Yet, as Williams, Stubbs & Milligan remark: "in some ways that is a large challenge"[181].

The NSW Chief Scientist and Engineer, in the Initial Report on the Independent Review of Coal Seam Gas Activities in NSW, suggests that "with application of best practice technologies and processes outlined in codes of practice, operators can minimise the risk of well failure and reduce environmental effects of CSG production".[182]

While well integrity has improved in the last decade, following the introduction of newer technologies and codes of practice which outline stricter standards for preparing wells,[183] "the legacy issue of exploration wells and decommissioned gas-field wells has not received adequate attention in terms of the means to maintaining their integrity indefinitely"[184].

Indeed, industry studies have concluded that the integrity of gas wells cannot be guaranteed over the long-term, due to the likelihood of failure in cement well casings over time.[185]

However, well failure can occur "in wells of any age",[186] including, in some cases, "before cement has set"[187].

Even a 'flawless' cement job can be damaged by routine well operations - with changing temperatures, pressures, and vibrations - causing the cement to expand, contract, crack and form minute openings, ultimately leading to gas migration.[188]

A recent US study of well leakages and violations in the Marcellus region of Pennsylvania, from 2010-2012, shows that about 6-7% of **new** gas wells had compromised structural integrity.[189] Similarly, an industry study on gas well casings published in the *Schlumberger OilField Review* in 2003, shows that 6% of **new** gas wells in the Gulf of Mexico experienced failure or leakage, with more than 50% of well casings failing after 15 years.[190] These casing failures occur in all types of wells, including both shallow and deep gas wells.[191] Identifying the precise cause of failure, as well as locating and repairing the leaks is often difficult and expensive.[192]

Another industry study has shown that well failure rates are increased in horizontal or deviated wells.[193] This is significant because lateral and horizontal wells are being used in the NSW Camden gas fields,[194] and are proposed as part of Santos' exploration expansion projects in the Pilliga.[195]

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